AD-A257 918

(2)

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 92 0952
6a. NAME OF PERFORMING ORGANIZATION Massachusetts Inst. of Tech. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NC
6c. ADDRESS (City, State, and ZIP Code) Haystack Observatory Cambridge, MA 02139	7b. ADDRESS (City, State, and ZIP Code) Building 410, Bolling AFB, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR 8b. OFFICE SYMBOL (If applicable) NC	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-89-0454
8c. ADDRESS (City, State, and ZIP Code) Building 410, Bolling AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2310; TASK NO. A2; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
RADAR-SATELLITE STUDIES OF THE HIGH-LATITUDE IONOSPHERE

12. PERSONAL AUTHOR(S)
John C. Foster

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/89 TO 8/92	92/10/15	

16. SUPPLEMENTARY NOTATION

DTIC ELECTE NOV 25 1992 S E

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Radar, multi-instrument, magnetosphere, ionosphere

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Emphasis has been placed on the analysis of multi-instrument experiments investigating the physics of the auroral oval/polar cap boundary and the vicinity of the plasmapause and inner edge of the ring current at mid-laitudes utilizing existing data sets from Millstone Hill and other incoherent scatter radars and available satellite overflights and supporting ground-based information. Ionospheric signatures of the cusp and the mechnaisms involved in large-scale plasma transport into the polar cap during magnetic storms have been investigated. Data from Air Force sensors on DMSP satellites have been combined with ground-based observations to examine intense oxygen ion outflow, localized intensifications of the convection electric field, and SAR arcs all of which occur equatorward of the main auroral enhancements during geomagnetic storms. The characteristics of the ring current and plasmasheet particle populations are closely coupled to these ionospheric phenomena.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL J G STOBIE, Lt Col, USAF	22b. TELEPHONE (Include Area Code) (202) 767-4960	22c. OFFICE SYMBOL AFOSR/NC

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

20 OCT UNCLASSIFIED

COMPLETED PROJECT SUMMARY

TITLE: Radar-Satellite Studies of the High-Latitude Ionosphere

PRINCIPAL INVESTIGATOR: Dr. J. C. Foster
M.I.T. Haystack Observatory
Westford, MA 01886

INCLUSIVE DATES: 1 August 1989 - 31 August 1992

GRANT NUMBER: AFOSR-89-0454

COSTS AND FY SOURCE:

$120,150	FY 89
$110,900	FY 90
$110,492	FY 91

SENIOR RESEARCH PERSONNEL:

Dr. J. C. Foster
Dr. J. M. Holt

JUNIOR RESEARCH PERSONNEL:

Dr. H.-C. Yeh
Ms. C.-N. Lue

PUBLICATIONS:

Aarons, J., J. C. Foster, A. S. Rodger, Auroral and Sub-Auroral F-Layer Irregularities and High Plasma During the Magnetically Active Periods of September 17-24, 1984, *Annales Geophysicae*, *9*, 614-627, 1991.

Foster, J. C., Storm-Time Plasma Transport at Mid and High Latitudes, *J. Geophys. Res.*, in press, 1992.

Lester, M., J. C. Foster, V. Wickwar, G. Gustafsson, Multi-Radar Study of Ionospheric Trough Dynamics during the SUNDIAL-86 Campaign, *Annales Geophysicae*, revised, 1990.

Lester, M., O. de la Beaujardiere, J. C. Foster, M. P. Freeman, H. Luhr, J. M. Ruohoniemi, and W. Swider, The Response of the Large-Scale Ionospheric Convection Pattern to Changes in the IMF and Substorms: Results from the SUNDIAL 1987 Campaign, *Annales Geophysicae*, submitted, 1992.

Yeh, H.-C., J. C. Foster, Storm Time Heavy Ion Outflow at Mid-Latitude, *J. Geophys. Res.*, *95*, 7881-7891, 1990.

Yeh, H.-C., J. C. Foster, J. M. Holt, R. H. Redus, and F. J. Rich, Radar and Satellite Observations of the Storm Time Cleft, *J. Geophys. Res.*, *95*, 12075-12090, 1990.

Yeh, H.-C., J. C. Foster, F. J. Rich, and W. Swider, Storm Time Electric Field Penetration Observed at Mid-latitude, *J. Geophys. Res.*, *96*, 12075-12090, 1991.

ABSTRACT OF OBJECTIVES AND ACCOMPLISHMENTS:

Emphasis has been placed on the analysis of multi-instrument experiments investigating the physics of the auroral oval/polar cap boundary and the vicinity of the plasmapause and inner edge of the ring current at mid-laitudes utilizing existing data sets from Millstone Hill and other incoherent scatter radars and available satellite overflights and supporting ground-based information. Ionospheric signatures of the cusp and the mechnaisms involved in large-scale plasma transport into the polar cap during magnetic storms have been investigated. Data from Air Force sensors on DMSP satellites have been combined with ground-based observations to examine intense oxygen ion outflow, localized intensifications of the convection electric field, and SAR arcs all of which occur equatorward of the main auroral enhancements during geomagnetic storms. The characteristics of the ring current and plasmasheet particle populations are closely coupled to these ionospheric phenomena.

FINAL SCIENTIFIC REPORT

submitted to the

Air Force Office of Scientific Research

by

Massachusetts Institute of Technology

for

AFOSR-89-0454

RADAR-SATELLITE STUDIES OF THE HIGH-LATITUDE IONOSPHERE

in

Fiscal Years 1989 - 1991

INTRODUCTION

Multi-instrument studies address short time scale variability over a large span of the high-latitude region. The two-dimensional character of the observation techniques used permit mapping between observation sites, thus placing detailed features in perspective and obtaining the greatest information from the available data. Important ionospheric phenomena, including large-scale plasma transport, spatial/temporal characteristics along the auroral oval/polar cap boundary, the generation of detached regions of enhanced ionization and irregularity-producing structures, and plasma wave processes and heating, are particularly amenable to study by multi-instrument techniques. Emphasis has been placed on the analysis of multi-instrument experiments investigating the physics of the auroral oval/polar cap boundary utilizing existing data sets from Millstone Hill and other incoherent scatter radars and available satellite overflights and supporting ground-based information.

RESEARCH ACTIVITIES

Radar-satellite studies during the February 8-9, 1986 great magnetic storm provide excellent examples of the application of multi-instrument techniques to investigate challenging magnetosphere-ionosphere coupling problems. The Millstone Hill radar operated throughout the storm period, observing a number of unusual phenomena. In-situ observations of ring current and plasma sheet particles, electric fields, and UV satellite images over the North American sector have been examined and a series of three research papers have been prepared based on this most interesting event.

A). Enhanced Heavy Ion Outflow

Local ionospheric observations with the Millstone Hill incoherent scatter radar have revealed an upward ion bulk velocity in excess of 3 km sec^{-1} at 1000 km altitude during the very large magnetic storm on 8 February 1986. The upward flux of O^+ ions exceeded 3×10^9 cm^{-2} sec^{-1} at 42° geodetic latitude (55°Λ) for a three-hour period around 18 MLT during the event. Figure 1 presents altitude profiles of ionospheric parameters observed over Millstone Hill with the zenith-directed 68 m antenna during this event. Frictional ion heating with ion temperatures in excess of 4000°K at 500 km altitude was observed by the radar in the vicinity of the ion outflow event and satellite observations place the ion outflow event within a region of intense ion and electron precipitation on field lines associated with the storm-perturbed ring current.

Yeh and Foster [1990] have examined this event and find that for a one-dimensional analysis of the observed plasma profiles, continuity considerations indicate a region of intense O^+ production ($200\ cm^{-3}\ sec^{-1}$) as well as significant upward acceleration ($5-10\ m\ sec^{-2}$) in the region between 600 km and 800 km altitude where the outflow approaches supersonic speed. Ionizing collisions and subsequent momentum transfer involving fast backsplash neutral O atoms produced by ring current heavy ion precipitation can account for the observed outflowing thermal O^+ fluxes in this case. Alternately, the outflow event can be explained in terms of a time-dependent diffusion process triggered by a sudden change in the frictional heating rate in the collision-dominated F region. These observations indicate that the mid-latitude ionosphere constitutes a significant source of upflowing thermal O^+ fluxes during intense magnetic storms.

B). Storm-Time Convection Electric field

Under disturbed geomagnetic conditions, the latitudinal profile of the westward ion convection (equivalent to poleward electric field) observed with the Millstone Hill incoherent scatter radar at dusk, often exhibits a double-peak (dual maxima). During the peak of the February 8-9, 1986 magnetic storm, the Millstone Hill radar was in the evening local time sector (16-22 MLT). Radar observations, reported by Yeh et al. [1990], indicate that high speed ($>1000\ m\ s^{-1}$) westward ion flow penetrated deeply below 50° invariant latitude (Λ) and persisted for 6 hours between 2100 UT on February 8, and 0300 UT on February 9. The double-peaked ion convection feature was pronounced throughout the period and the separation in the dual maxima ranged from 4° to 10°. Figure 2 presents the radar-deduced latitude variation of westward plasma convection velocity and F region plasma density for two such events along with ion and electron particle data obtained during overflights of the DMSP satellites.

During the February, 1986 storm the latitude positions of the high-latitude ion drift peak and the convection reversal varied in unison. The low-latitude ion drift peak ($\sim 49°\Lambda$ or L=2.3) did not show significant UT/MLT variation in its latitude location, but showed a decrease in magnitude during the initial recovery phase of the storm. Using simultaneous particle (30 eV - 30 keV) precipitation data from the DMSP F6 and F7 satellites, we find the high-latitude ion drift peak to coincide with the boundary plasma sheet/central plasma sheet transition in the high ionospheric conductivity (>15 mhos) region. The low-latitude ion drift peak lay between the equatorward edges of the electron and soft (< 1 keV) ion precipitation in the low conductivity region (~1 mho). A comparison between the low-altitude observations and simultaneous ring current observations from the high-altitude AMPTE satellite

further suggests that the low-latitude ion drift peak is collocated in magnetic latitude with the maximum of the O^+ dominated ring current energy density. The low-latitude ion drift peak is the low-altitude signature of the electric field shielding effect associated with ring current penetration into the outer layer of the storm time plasmasphere. Unlike the transient and localized subauroral ion drifts (SAID), the intense westward ion drifts developed in response to heavy ion ring current shielding during a great magnetic storm can decouple from the high latitude electric field and penetrate to very low-latitudes, and persist for long durations in the dusk and early afternoon MLT sectors. The resultant westward ion convection can have profound effects on the transport of dayside F-region plasma toward the polar cap and on the generation of heavy ion outflows at mid-latitudes.

C). Multi-Instrument Studies of the Cleft Ionosphere

During the magnetic storm of February 8-9, 1986, the region of strong ion convection in the vicinity of the dayside cusp expanded equatorward into the field of view of the Millstone Hill radar at lower mid-latitudes. High-speed (>1.5 km s^{-1}) poleward ion flows were found at latitudes as low as 60° invariant latitude, at least 10° lower than the typical cleft/cusp position for moderately disturbed ($Kp>4$) magnetospheric conditions. The ion velocity pattern responded promptly to changes in the interplanetary magnetic field *By* direction. The large-scale two-dimensional convection pattern across the dayside was well resolved using radar azimuth scan data at Millstone Hill, thus enabling us to place the fine-scale radar/satellite observations of the storm time cusp and cleft in the context of the large-scale pattern. Yeh et al [1991] presented a detailed comparison of radar and DMSP F7 satellite observations in the prenoon sector during a period of $Kp > 7$, to examine the low-altitude signatures of various plasma regions in the vicinity of the cusp. The combination of particle precipitation, magnetic field perturbation, radar measurements of ion heating, and convection consistently suggests the unusual low-latitude position of cusp at 65° invariant latitude. Boundary plasma sheet particles were observed to coincide with a narrow region of magnetic-field-aligned currents, and with antisunward convection flows at the equatorward edge of the cleft. The radar and satellite observations indicate that the storm time cleft and cusp at ionospheric altitudes retain the general characteristics revealed in their average configuration. Particle and field signatures of the plasma sheet, plasma sheet boundary layer, low-latitude boundary layer, cusp, and mantle were identified at unusually low magnetic latitude in the 9-10 magnetic local time sector during this event.

D). Studies of the Cusp and Polar Cap Boundary

Azimuth scanning experiments with incoherent scatter radars can produce two-dimensional maps of plasma characteristics and electric fields which span the auroral oval - polar cap boundary in the vicinity of the dayside cusp and cleft. The Atmospheric Sciences group at Millstone Hill has pursued a series of investigations of this important region using combined radar and satellite data sets and this work is continuing with a study of plasma transport into the polar cap from the low latitude F region. Initial results suggest that this mechanism constitutes an important source for the polar cap ionization patches which lead to irregularity growth and intense polar scintillations. Figure 3 presents a radar elevation scan which reveals dramatic ionospheric density structure in the vicinity of the noontime cleft during an intense magnetic storm. Observations of the convection electric field associated with this region show that such discrete, intense density enhancements are transported rapidly poleward into the polar cap. Foster [1992] has described the occurrence of such effects at mid and high-latitudes.

E.) Satellite/Ground Observations of a SAR Arc

Extensive incoherent scatter radar data were obtained during multi-radar World Day operations during a major magnetic storm in March, 1990. DMSP satellite overflights through the field of view of ground-based radar and optical observatories at Millstone Hill have been analyzed during the occurrence of a stable auroral red (SAR) arc near the Millstone latitude. Figure 4 presents simultaneous data obtained during this event which co-locates the SAR arc with a deep ionospheric trough and a localized enhancement of sunward convection, equatorward of the auroral particle pecipitation. These conditions are similar to those discussed by Yeh et al [1991] and discussed in section B, above. Radar and optical observations monitored the SAR arc for over 4 hours and a detailed analysis of the event is proceding.

Research Papers Generated Under AFOSR-89-0454

Aarons, J., J. C. Foster, A. S. Rodger, Auroral and Sub-Auroral F-Layer Irregularities and High Plasma During the Magnetically Active Periods of September 17-24, 1984, *Annales Geophysicae*, *9*, 614-627, 1991.

Foster, J. C., Storm-Time Plasma Transport at Mid and High Latitudes, *J. Geophys. Res.*, in press, 1992.

Lester, M., J. C. Foster, V. Wickwar, G. Gustafsson, Multi-Radar Study of Ionospheric Trough Dynamics during the SUNDIAL-86 Campaign, *Annales Geophysicae*, revised, 1990.

Lester, M., O. de la Beaujardiere, J. C. Foster, M. P. Freeman, H. Luhr, J. M. Ruohoniemi, and W. Swider, The Response of the Large-Scale Ionospheric Convection Pattern to Changes in the IMF and Substorms: Results from the SUNDIAL 1987 Campaign, *Annales Geophysicae*, submitted, 1992.

Yeh, H.-C., J. C. Foster, Storm Time Heavy Ion Outflow at Mid-Latitude, *J. Geophys. Res.*, *95*, 7881-7891, 1990.

Yeh, H.-C., J. C. Foster, J. M. Holt, R. H. Redus, and F. J. Rich, Radar and Satellite Observations of the Storm Time Cleft, *J. Geophys. Res.*, *95*, 12075-12090, 1990.

Yeh, H.-C., J. C. Foster, F. J. Rich, and W. Swider, Storm Time Electric Field Penetration Observed at Mid-latitude, *J. Geophys. Res.*, *96*, 12075-12090, 1991.

Travel Supported by AFOSR-89-0454

October, 1989, Huntsville, Al.: H. C. Yeh to attend Workshop on Magnetosphere/Ionosphere Plasma Models (paper presented).

December, 1989, San Francisco, Ca.: J. Holt to attend Fall Annual Meeting of AGU (paper presented).

December, 1989, San Francisco, Ca.: J. Foster to attend Fall Annual Meeting of AGU (partial support).

January, 1990, New London, Ct.: J. Foster to ELF Workshop.

May, 1990, Washington, D.C.: J. Foster to attend Ionospneric Effects Symposium (partial support).

June, 1991, London, Ontario: J. Foster to attend 1991 North American URSI Meeting (paper presented).

May 1992, Montreal, Quebec: J. Foster to attend 1992 AGU Spring Meeting.

Professional Personnel

Dr. J. C. Foster - Principal Investigator

Dr. J. M. Holt - Senior Research Scientist

Dr. H.-C. Yeh - Research Scientist

Ms. C.-N. Lue (applications programming)

Scientific Interactions

1. Spoken Papers:

"Scanning Radar Observations of Ionospheric Convection at the Auroral Oval - Polar Cap Boundary", (J. Foster), 1991 North American URSI Meeting, London, Ont., June, 1991 (invited).

"How wide is the Cusp? - Radar Observations", (J. Foster), GEM Workshop, Weston, Mass. Oct., 1990 (invited).

"Millstone Hill Observations of Storm-Related Ionospheric Perturbations", (J. Foster), XXIII URSI General Assembly, Prague, Aug., 1990.

"Millstone Hill Observations of Storm-Related Ionospheric Perturbations at Mid-Latitudes", (J. Foster, H.-C. Yeh, M. Buonsanto, J.Klobuchar, and W. Swider Jr.),AGU, Baltimore, May, 1990 (invited).

"Determination of Daytime Midlatitude Electron Density Profiles from Limited Real-Time Measurements", (D. Decker, J. Jasperse, D. Anderson, F. Rich, and J. Foster), AGU, San Francisco, December, 1989.

"Storm-Time Electric Field Penetration Observed at Mid-Latitude", (H.-C. Yeh, and J. Foster), AGU, San Francisco, December, 1989.

"Radar-Satellite Observations of Nightside Auroral Boundaries", (J. Foster, H.-C. Yeh, R. Eastes, and F. Rich), AGU, San Francisco, December, 1989.

"Storm-Time Heavy Ion Outflow at Mid-Latitude", (H.-C. Yeh, and J. Foster), Workshop on Magnetosphere/Ionosphere Plasma Models, Huntsville, Oct., 1989.

2. Consultative and Advisory Functions:

a) Calibration of AFGL ionospheric model based on DMSP in-situ observations; AF/AFGL personnel: J. Jasperse, D. Decker., F. Rich

b) Comparison of Millstone Hill radar scan maps with Polar BEAR UV auroral imagery and DMSP in-situ observations; AF/AFGL personnel: R. Eastes, F. Rich.

c) QUIMMS overflight campaign; AF/AFGL personnel: D. Hunton.

d) CIRRIS overflight campaign; AF/AFGL personnel: J. Wise, R. Nadile

e) CRRES data exchange; AF/AFGL personnel: E. Weber, H. Singer

f) Ionospheric Tomography; AF/AFGL personnel: J. Klobuchar

g) DMSP SAR arc analysis; Phillips Lab: W. Denig, F. Rich

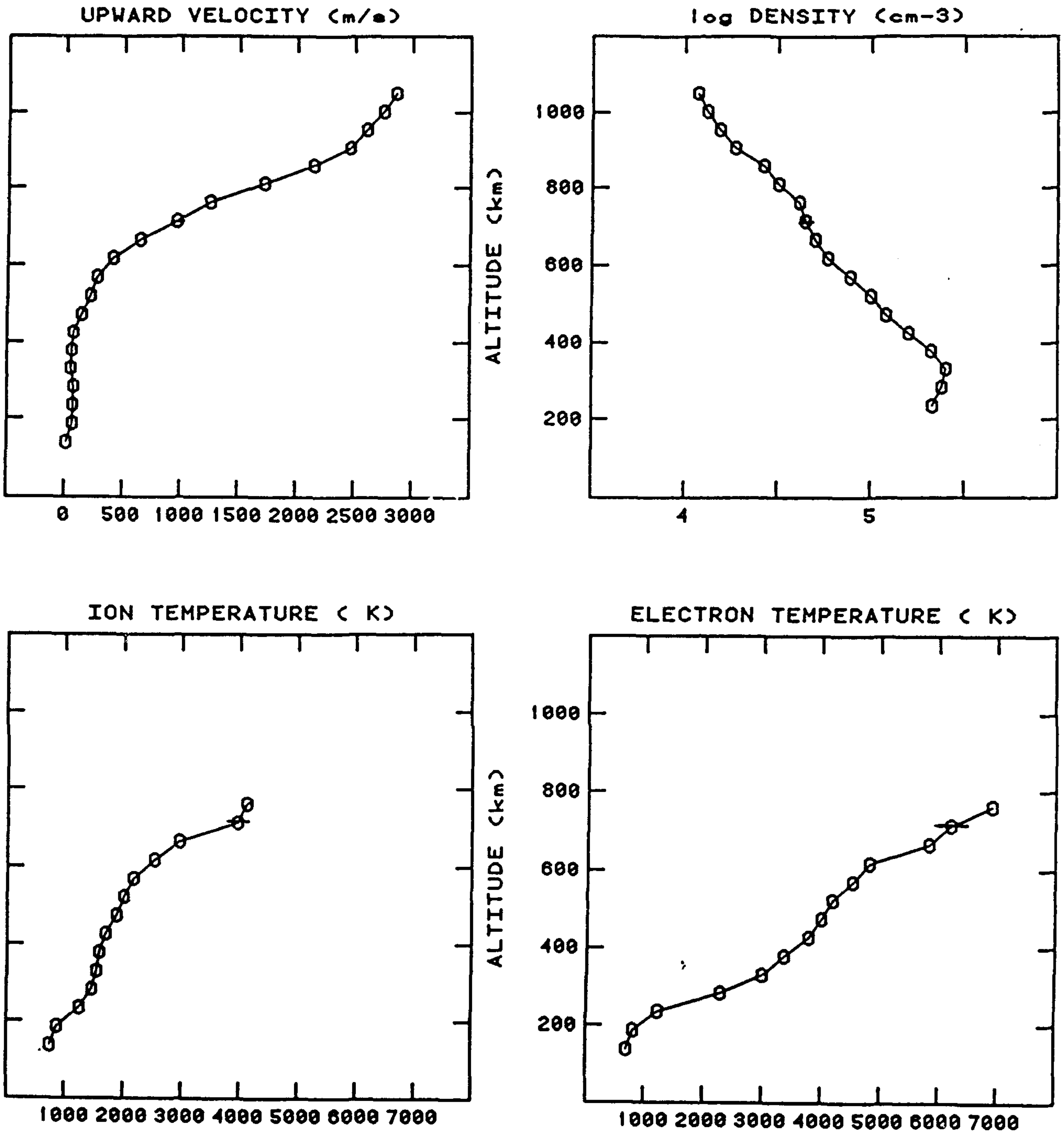


Figure 1. Altitude profiles of ionospheric plasma parameters obsrved with the Millstone Hill zenith-directed antenna during the large magnetic storm of Feb. 8, 1986. Between 600 km and 800 km the upward-directed velocity increases to >2000 ms-1 and ion and electron temperatures exceed 4000°K and 7000°K, respectively [Yeh and Foster, 1990].

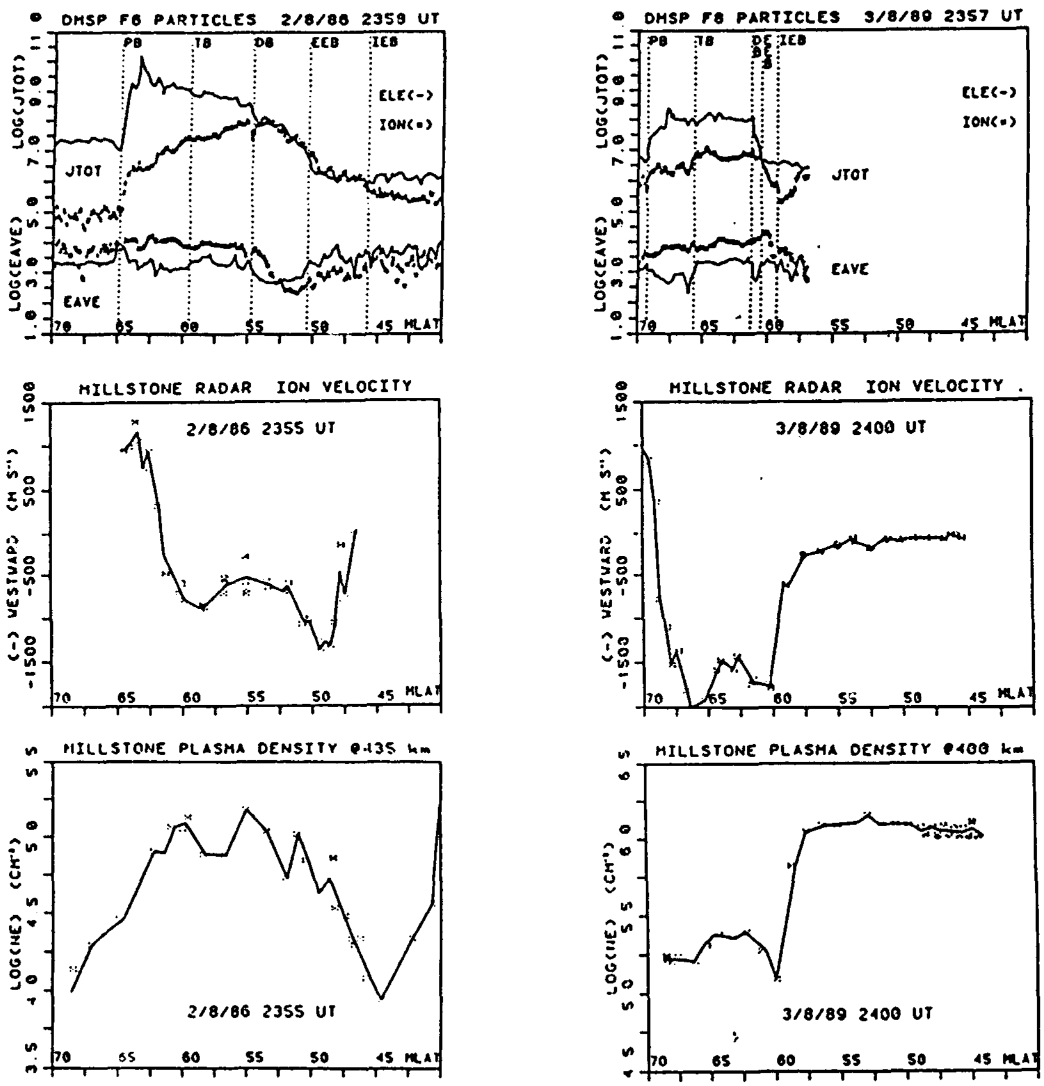
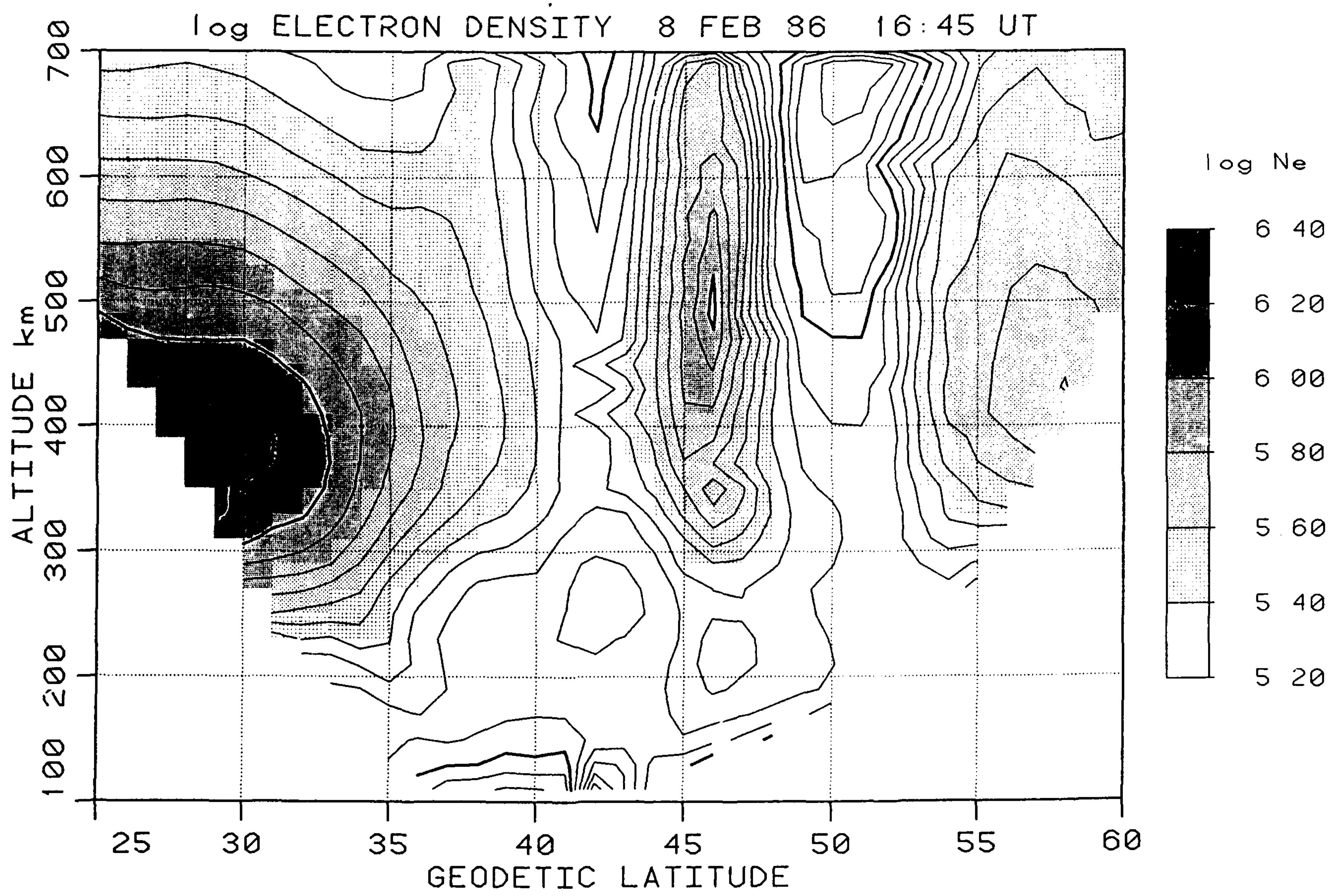
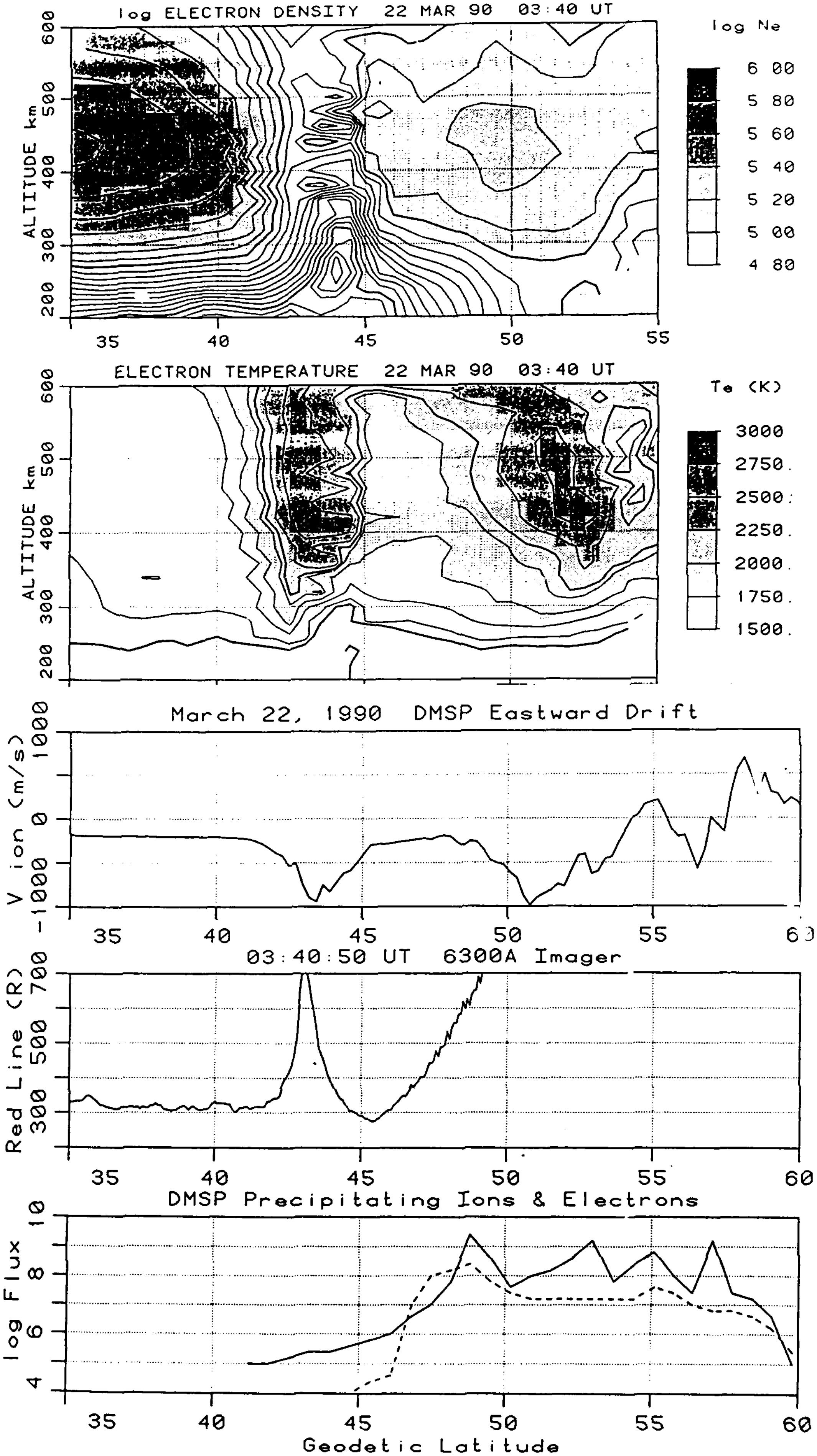


Figure 2. Combined radar - satellite observations for magnetic storm (left) and substorm (right) conditions in which a double-peaked latitude structure develops in the ionospheric sunward plasma convection region at dusk. The low latitude enhancment in westward convection lies near the plasmapause and outer edge of the ring current, between the l w-latitude electron and ion precipitation boundaries [Yeh et al., 1990b]


log ELECTRON DENSITY 8 FEB 86 16:45 UT
ALTITUDE km
700
600
500
400
300
200
100
25
30
35
40
45
50
55
60
GEODETIC LATITUDE
log Ne
6 40
6 20
6 00
5 80
5 60
5 40
5 20


log ELECTRON DENSITY 22 MAR 90 03:40 UT
ALTITUDE km
log Ne
6.00
5.80
5.60
5.40
5.20
5.00
4.80
ELECTRON TEMPERATURE 22 MAR 90 03:40 UT
Te (K)
3000
2750.
2500.
2250.
2000.
1750.
1500.
March 22, 1990 DMSP Eastward Drift
V ion (m/s)
03:40:50 UT 6300A Imager
Red Line (R)
DMSP Precipitating Ions & Electrons
log Flux
Geodetic Latitude